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Effect of various fire retardants on surface roughness of plywood

Nadir Ayrilmis[a,*], Suleyman Korkut[b], Ercan Tanritanir[c], Jerrold E. Winandy[d],
Salim Hiziroglu[e]

[a]*Istanbul University, Forestry Faculty, Department of Wood Mechanics and Technology, Bahcekoy, Sariyer, 34473, Istanbul, Turkey*
[b]*Abant Izzet Baysal University, Forestry Faculty, Department of Wood Mechanics and Technology, Duzce 81620, Turkey*
[c]*Istanbul University, Forestry Faculty, Department of Forest Products Industry, Machinery and Business Administration, Bahcekoy,
Sariyer, 34473, Istanbul, Turkey*
[d]*USDA Forest Service, Forest Products Laboratory, Madison, WI 53726-2398, USA*
[e]*Oklahoma State University, Department of Forestry, Stillwater, OK 74078-6013, USA*

Abstract

In this study the surface roughness of plywood treated with various fire retardants was investigated. Commercially manufactured veneer of Akaba wood (*Tetraberlinia bifoliolata*) was treated with borax, boric acid, monoammonium phosphate and diammonium phosphate, then experimental plywood panels were made from these veneer sheets. A stylus method was employed to evaluate the surface characteristics of the samples. Three main roughness parameters, mean arithmetic deviation of profile (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}) obtained from the surface of plywood were used to evaluate the effect of chemical treatments on the surface characteristics of the specimens. Significant difference was determined ($p = 0.05$) between surface roughness parameters (R_a, R_z, R_{max}) for four treatments and two retentions of fire retardants. Samples treated with 3% concentration of borax had the smoothest surface with 11.09 μm R_a while the roughest surface was found for the samples treated with 6% boric acid having R_a value of 12.44 μm. Results revealed that the surface quality of the panels reduced with increasing chemical concentration.
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1. Introduction

Surface roughness of veneer plays an important role in plywood manufacture. Cross grain, annual ring width, rays, knots, reaction wood, ratio of early wood and late wood, pre-treatment and peeling conditions, such as knife angle, are some of the raw material and production parameters influencing roughness of veneer. Control of veneer surface in plywood production is essential to maintain plywood quality [1]. Rough veneers reduce contact between the layers resulting in a weak glueline and low strength properties of the plywood [2]. Veneer with a rough surface can also cause excessive resin use and may result in resin-bleed through the face veneer. Roughness of face veneer can be improved to a certain extend by sanding. However, this increases overall production cost [3,4]. Surface of wood products may be characterized by either topography or profile. Profiles are more widely used in evaluating surface irregularities since less expensive data acquisition equipment is required with the profile measurement in comparison to that of topography. Stylus technique among the other methods, such as pneumatic, laser, and acoustic emission, is accurate, practical, and repeatable.

*Corresponding author. Tel.: +90 212 226 1100;
fax: +90 212 226 1113.

E-mail addresses: nadiray@istanbul.edu.tr (N. Ayrilmis),
korkut_suleyman@yahoo.co.uk (S. Korkut), jwinandy@fs.fed.us,
jwinandy@wisc.edu (J.E. Winandy), hizirog@okstate.edu
(S. Hiziroglu).

Quantitative roughness parameters can be accurately calculated from the actual graph obtained from the surface and all standard parameters can be generated to have an objective information about the surface measured [5–7]. Different techniques including stylus method were used in various studies to measure and quantify surface characteristics of wood and wood-based panels [8–11]. Roughness of southern pine veneer surfaces using a stylus tracing method was also evaluated in another study [7]. Knife setting and cutting speed were adjusted based on the roughness measurements of veneer in this work. Pneumatic method was also applied to wood surface to evaluate irregularities caused by sawing [12].

The use of plywood treated with fire retardants are becoming popular. They are very important for specialized construction applications and furniture industry [13,14]. Various types of thin overlays or finishes are sometimes directly applied to the sanded surface of fire retardant treated panels. Therefore, the surface quality of the plywood panels plays an important role for further applications. The objective of this study is to evaluate surface roughness of plywood samples made from veneer treated with four different fire retardants by using a fine stylus tracing techniques. The influence of these chemical treatments on the surface roughness of experimental plywood was quantified based on three roughness parameters obtained from the stylus type profilometer.

2. Material and methods

2.1. Plywood manufacture

Commercially manufactured rotary cut veneer of Akaba (*Tetraberlinia bifoliolata*) logs were used to make plywood under laboratory conditions. Veneer samples were kept in a conditioning chamber until they reach 7% moisture content. In the next step, the specimens were soaked for 3 h in plexiglass boxes while laid horizontally 4 cm apart from each other in 3% or 6% aqueous solutions of borax ($Na_2B_4O_7 \cdot 10H_2O$) or boric acid (H_3BO_3), or in 3% or 11% aqueous solutions of monoammonium phosphate ($NH_4H_2PO_4$) or, diammonium phosphate (($NH_4)_2HPO_4$). The temperature of the various solutions was 60 °C during the treatment process. Each treated veneer sample was then reconditioned to 7% moisture content before plywood panels were manufactured. Before and after treatment process samples were weighted to calculate chemical retention. A total of 36 five-ply experimental panels, four for each treatment were manufactured from the veneer with the dimension of 490 mm × 490 mm × 2.20 mm. Exterior resin phenol formaldehyde with 47% solid content was applied to the veneers at a rate of $200 \, g/m^2$ and they

were pressed using a pressure of 65 bar at a temperature of 130 °C for 12 min in a computer controlled laboratory press. Plywood panels were conditioned at 20 °C of temperature and 65% relative humidity for three weeks before initial surface roughness evaluations were carried out.

2.2. Determination of surface roughness

Ten 100 mm × 100 mm surface roughness test samples were cut from each panel. One measurement was performed on each surface roughness test sample across the grain orientation of the top ply. A total of 40 roughness measurements along and across the grain orientation of the surface of each type of treated samples and control samples were taken using a stylus type profilometer, Mitutoyo Surftest SJ-301 (Fig. 1). Tracing speed, stylus tip diameter, and tip angle were 10 mm/min, 4 μm and 90°, respectively. Fifteen millimeter tracing length (L_t) with 2.5 mm cut-off was used for the measurements. The measuring force of the scanning arm on the surfaces was 4 mN (0.4 g) which did not put any significant damage on the surface [15]. Measurements were repeated whenever the stylus tip fell into the cell lumen for several times during the tests. The calibration of the instruments was checked every 100 measurements by using a standard reference plate with R_a values of 3.02 and 0.40 μm. Fig. 2 illustrates a typical roughness profile for an untreated control and for plywood samples treated with 6% aqueous solution of boric acid. Three roughness parameters, mean arithmetic deviation of profile (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}) were commonly used in previous studies to evaluate surface characteristics of wood and wood composites including veneer [7,11,17,18]. R_a is the average distance from the profile to the mean line over the length of assessment. R_z can be calculated from the peak-to-valley values of five equal lengths within the profile while maximum roughness (R_{max}) is the distance between peak and valley points of the profile which can be used as an indicator of the maximum defect height within the assesed profile [19].

Therefore, such parameters which are characterized by ISO 4287 [16] were also employed to evaluate influence of chemical treatment on the surface roughness of plywood specimens. The specifications of these parameters are described in details in various works [17–19]. Analysis of variance (ANOVA) was used for the statistical analysis. Also all multiple comparisons were individually evaluated and significance differences between only the average values R_a, R_z, and R_{max} of roughness parameters between the surface of control and treated samples were determined using Duncan's multiply range test.
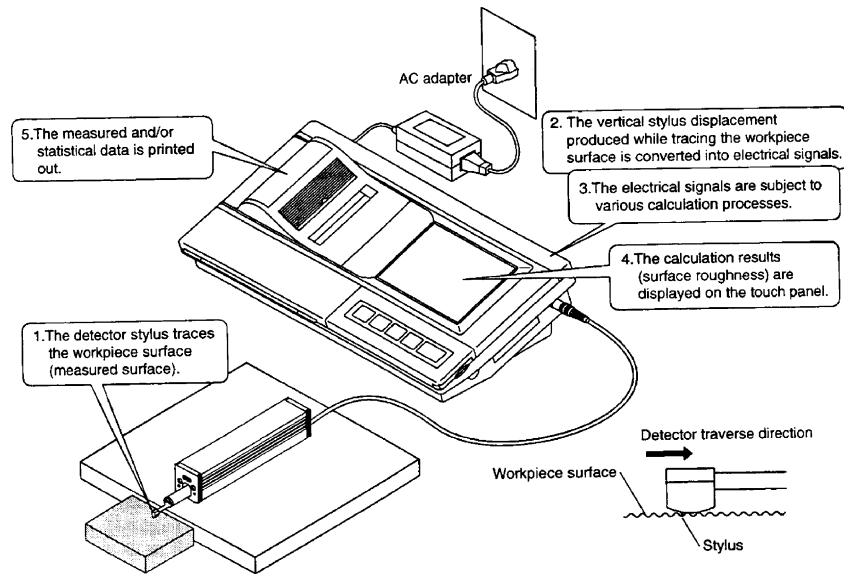
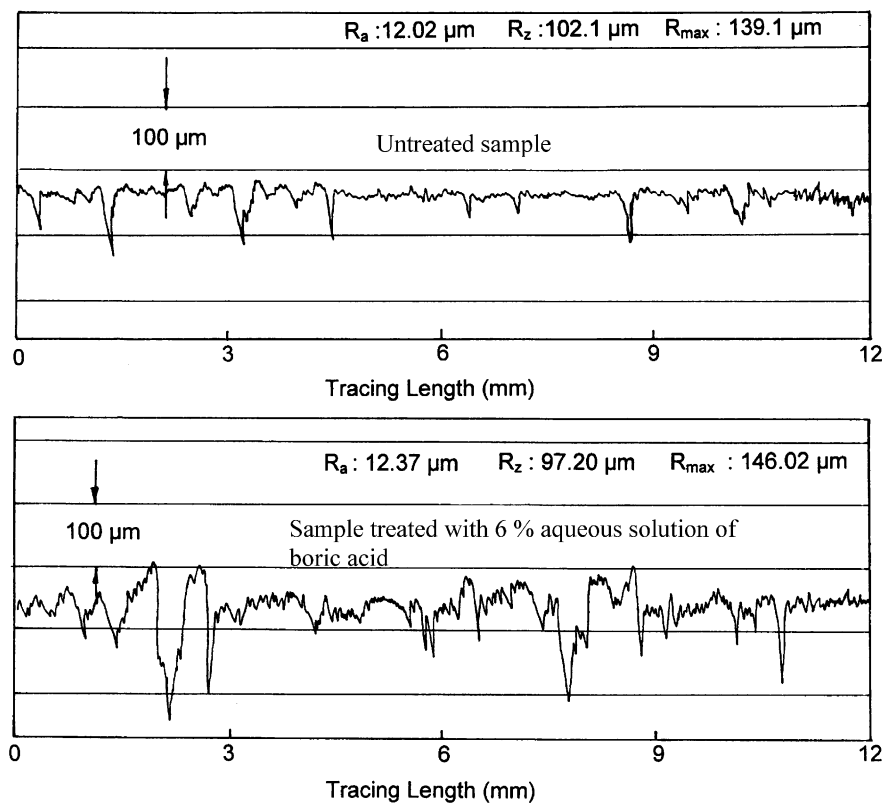Fig. 1. Outline of the stylus type profilometer—Mitutoyo Surftest SJ-301.

Fig. 2. Surface roughness profiles of treated with 6% aqueous solutions boric acid and untreated samples.

3. Results

Table 1 and Fig. 3 show results of average chemical retention values and surface roughness parameters of the panels. Significant difference was determined ($p = 0.05$) between surface roughness parameters (R_a, R_z, and R_{max}) for four treatments and two retentions of fire retardants according to the ANOVA statistical analysis (Table 2). Homogeneity groups were determined individually for R_a, R_z and R_{max} by Duncan's multiply range test.

Table 1
Retention values as function of chemical concentration and average values of roughness parameters

Treatment chemical	Retention (kg/m^3)	Aqueous solutions (%)	Roughness parameters		
			R_a (μm)	R_z (μm)	R_{max} (μm)
Untreated	—	—	10.13 F (12.17)	88.81 DEF (10.19)	123.00 CD (12.11)
Borax	8.60	3	11.09 DE (10.48)	91.01 CE (12.55)	125.42 BCD (12.23)
Borax	14.54	6	12.01 AB (10.21)	102.03 AB (10.10)	133.08 A (9.95)
Boric acid	11.07	3	11.58 BCD (9.42)	98.26 B (9.25)	130.99 AB (9.48)
Boric acid	19.37	6	12.44 A (10.48)	104.01 A (8.21)	134.52 A (9.07)
MAP	21.83	3	11.39 CE (8.17)	91.65 CD (11.41)	123.90 CD (12.63)
MAP	37.63	11	12.14 A (8.71)	98.53 B (9.21)	131.09 AB (8.80)
DAP	25.57	3	11.50 BCE (10.11)	93.71 C (8.90)	121.07 D (9.01)
DAP	41.81	11	11.90 AC (11.01)	85.24 F (9.98)	118.62 CD (8.90)

n: 40. Numbers in parentheses are standard deviations.
Homogeneity groups: same letters in each columns indicate that there is no statistical difference between the samples according to the Duncan's multiply range test.
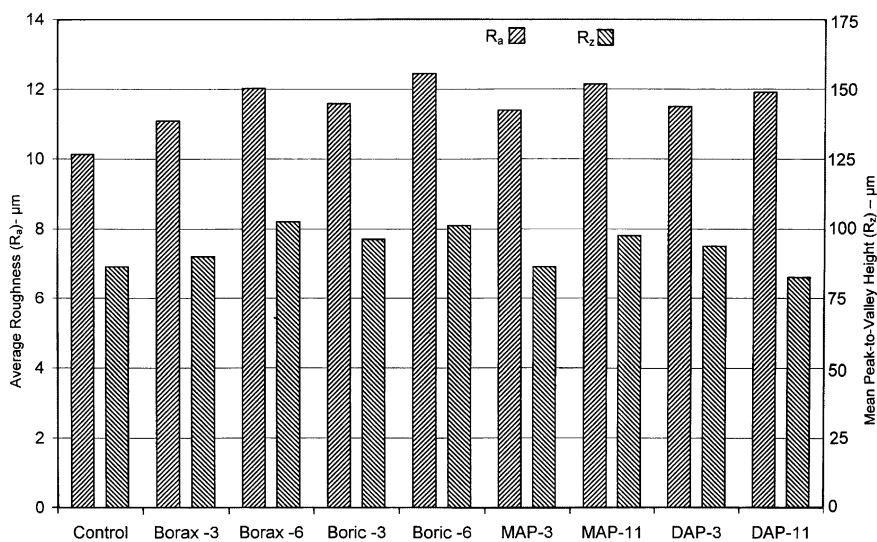

Fig. 3. Average values of R_a and R_z parameters.

Table 2
Analysis of variance for R_a, R_z, and R_{max} roughness parameters

Roughness parameter	Source of variation	Degree of freedom	Sum of squares	Mean square	F-ratio (95%)
R_a	Between treatments	8	148.76	18.595	14.865
	Within treatments (Error)	351	439.07	1.251	>
	Total	359	587.83	19.846	2.016
R_z	Between treatments	8	12624.68	1578.08	17.781
	Within treatments (Error)	351	31150.99	88.75	>
	Total	359	43775.67	1666.83	2.016
R_{max}	Between treatments	8	10373.82	1296.72	8.137
	Within treatments (Error)	351	55935.80	159.36	>
	Total	359	66309.62	1456.08	2.016

3.1. Average surface roughness (R_a)

R_a values of all treated samples (eight groups: four treatments and two retentions) showed a significant difference as compared to untreated sample according to the Duncan's multiply range test, as shown in Table 1. The treated specimens had significantly higher average surface roughness (i.e., rougher R_a) than that of untreated samples. The R_a values for the borax, boric acid, monoammonium phosphate (MAP), and diammonium phosphate (DAP) at higher concentration (6% or 11%) are always rougher than the lower concentrations (3%). Average retention value of the samples treated with 3% concentration of borax was determined as $8.60 \, \text{kg/m}^3$. These samples had also the smoothest surface of any treated specimens with $11.09 \, \mu\text{m} \, R_a$. As concentration of borax was doubled, retention of the samples increased 1.69 times and average R_a values also increased 9.08%. Increased solution concentration of boric acid also adversely influenced surface quality of the samples. Samples treated with 3% concentration of boric acid had the roughest surface with R_a value of $12.44 \, \mu\text{m}$. Samples treated with 11% concentration of MAP and DAP resulted in rougher surface with R_a than those of treated with 3%. As retention of the samples treated MAP and DAP increased 1.72 and 1.64, their average R_a values increased 7.4 and 3.95, respectively. Although samples treated with 11% concentration of MAP and DAP had the highest chemical retention level (37.63 and $41.81 \, \text{kg/m}^3$) among all treated samples, their R_a values were lower than those of treated with 6% concentration of boric acid ($19.37 \, \text{kg/m}^3$). Samples treated with 6% boric acid and 11% MAP, and DAF were not significantly different relating to R_a as can be seen in Table 1.

3.2. Mean peak-to-valley values (R_z)

The R_z value of $85.24 \, \mu\text{m}$ of samples treated with 11% concentration of DAP had the lowest value among the treated and untreated samples. It was determined a significant difference among the treatment groups. R_z values of 3% concentration of MAP, 3% borax, and 11% DAP and the untreated control are the same, while R_z values of the other treated samples are significantly different to the untreated control sample (Table 1). Samples treated with 6% concentration of boric acid had the highest R_z value of $104.01 \, \mu\text{m}$ with and same with 6% concentration of borax of 102.03. The R_z values of borax, boric acid, and MAP at higher concentration (6% or 11%) were always rougher than the lower concentrations (3%) except for 11% concentration of DAP. However, the R_z value of the samples treated with DAP does not follow this trend. The R_z value of the samples treated with 11% concentration of DAP were lower than that of treated with 3%

Table 3
Increase of R_a values as function of chemical concentration

Treatment chemical	Aqueous solution	Increase of roughness parameters		
		R_a (%)	R_z (%)	R_{max} (%)
Borax	3	9.48	2.48	1.97
Borax	6	18.56	14.89	8.20
Boric acid	3	14.31	10.64	6.50
Boric acid	6	22.80	17.12	9.37
MAP	3	12.44	3.20	0.73
MAP	11	19.84	10.94	6.58
DAP	3	13.52	5.52	−1.57
DAP	11	17.47	−4.02	−3.56

concentration of it. When eventual chemical retention increased 1.69, 1.75, 1.72 times for borax, boric acid, and MAP, the R_z value of the treated samples increased 12.41%, 6.48%, 7.74%, respectively (Table 3).

3.3. Maximum roughness values (R_{max})

The R_{max} values of all treated samples were higher than that of untreated sample except for treatments which were 3% and 11% concentration of DAP. R_{max} values of 3% concentration of MAP, 3% borax, and 3% and 11% DAP and the untreated control are the same, while R_{max} values of the other treated samples are significantly different to the untreated control sample. Samples treated with 6% concentration of boric acid had the highest R_{max} value of $134.52 \, \mu\text{m}$ like R_a, R_z. Increased solution concentration of fire retardants adversely influenced R_{max} values of the samples except for DAP. Borax, MAP, and DAP follow R_{max} value of boric acid. Retention of the samples increased 1.69, 1.75, 1.72 times for borax, boric acid, and MAP, the R_{max} value of the treated samples increased 6.23%, 2.87%, and 5.85%, respectively. However, R_{max} value of the samples with treated DAP decreased with increasing chemical concentration as shown in Table 1.

4. Conclusions and further work

This study evaluated surface roughness of plywood treated with four fire retardants. Three roughness parameters could be used as an indicator to quantify the surface characteristics of the treated samples. It was found that such parameters are able to differentiate the surface roughness of the panels due to different retention and concentration levels. All of the treatments adversely effected surface roughness of the panels except for DAP 11% (R_z and R_{max}) and DAP 3% (R_{max}) treatments. However, negative influence of boric acid on the surface roughness was the highest among all chemicals used for the treatment followed by monoammonium phosphate and borax.

Previous work on FRT blockboard plywood found that increased chemical concentrations gave higher retention values which in turn resulted in better fire resistance characteristics of the samples [20]. However, this study indicates that surface roughness of the panels can be adversely influenced by increased concentrations of fire retardants. Therefore, chemical concentration should be carefully adjusted to provide sufficient fire retardancy for treated plywood while also providing minimal negative effects on its surface roughness. Further studies performed to use treatment of the panels should evaluate more than two concentrations of chemicals to attain a better understanding of the effect of treatment variables on the surface quality of the panels. Also other roughness parameters such as maximum valley height and core roughness can be included to have detailed information about the treated surfaces.

Acknowledgements

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